Perioperative ischemia and cardiac complications in major vascular surgery: Importance of the preoperative twelve-lead electrocardiogram

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Purpose: To investigate the associations between specific preoperative 12-lead electrocardiogram (ECG) abnormalities, perioperative ischemia, and postoperative myocardial infarction or cardiac death in major vascular surgery.

Methods: Two prospective studies on perioperative myocardial ischemia performed in two tertiary university hospitals were combined to include 405 patients. All preoperative ECGs were analyzed according to the Sokolow-Lyon criteria for left ventricular hypertrophy by investigators who were blinded to the patients' perioperative clinical course. Perioperative myocardial ischemia was detected by continuous ECG recording, and postoperative cardiac complications included myocardial infarction and cardiac death.

Results: A total of 19 postoperative cardiac complications occurred (two cardiac deaths and 17 myocardial infarctions). Voltage criteria for left ventricular hypertrophy (78 patients, 19%) and ST segment depression greater than 0.5 mm (98 patients, 24.2%) on preoperative ECGs were both significantly associated with postoperative myocardial infarction or cardiac death (odds ratio, 4.2 and 4.7; $p = 0.001$ and 0.0005, respectively) and with longer intraoperative and postoperative myocardial ischemia. In each of the two study groups, a preoperative ECG abnormality that involved voltage criteria, ST segment depression, or both (134 patients, 33.1%) was more predictive of postoperative cardiac complications than any other preoperative clinical variable, including a history of myocardial infarction or angina pectoris, diabetes mellitus, pathologic Q-wave by ECG, or preoperative myocardial ischemia. The combined duration of intraoperative and postoperative ischemia and the preoperative ECG with either voltage criteria or ST segment depression were the only independent factors associated with adverse cardiac events by multivariate analysis ($p \leq 0.0001$ and $p = 0.02$, respectively).

Conclusion: Left ventricular hypertrophy and ST segment depression on preoperative 12-lead ECGs are important markers of increased risk for myocardial infarction or cardiac death after major vascular surgery. (J Vasc Surg 1997;26:570-8.)

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Ischemic cardiac complications are among the leading causes of perioperative morbidity and death and thus contribute a significant burden to in-hospital resources and cost of care.[1,2]

This tendency is expected even to expand in the near future as a result of the increasing age of the population and the growing number of subjects with coronary artery disease who undergo major surgery.[3] In the past two decades intense clinical and investigational effort was centered on the identification and possible treatment of preoperative cardiac risk factors.[2] The problem of how to identify patients who

may benefit from additional, often costly, preoperative testing and from coronary revascularization procedures before undergoing noncardiac surgery is still a matter of dispute, especially when dealing with high-risk patients such as those who require major vascular surgery.[4] To date, only two risk factors for perioperative cardiac morbidity have been clearly identified: recent myocardial infarction and current congestive heart failure.[3] Other markers such as hypertension, diabetes, angina pectoris, and a history of myocardial infarction, which are known risk factors for long-term cardiac morbidity and death in the nonoperative setting, do not consistently correlate with postoperative cardiac complications.[2,3] Similarly, the use of more sophisticated and costly testing methods, including exercise stress test,[5] thallium imaging,[6,7] dobutamine echocardiography,[8] and preoperative Holter monitoring,[9] has been questioned,[1,4] and they are not routinely performed in most medical centers.

Recent studies have shifted the focus of clinical investigation to the perioperative period, showing that postoperative silent myocardial ischemia, and particularly long-duration ischemia, more reliably predict ischemic cardiac complications than any preoperative predictor.[10-12] Yet the pathogenesis of postoperative myocardial infarction and the nature of its association with perioperative myocardial ischemia remains unclear.

Electrocardiogram (ECG) abnormalities, including left ventricular hypertrophy, nonspecific ST-T wave changes, and pathologic Q-waves, are associated with a poor long-term cardiac prognosis in the general population.[13,14] Despite its routine use to detect patients with heart disease, the value of preoperative ECG in predicting postoperative cardiac complications in patients who are already known or highly suspected to have coronary artery disease has not been rigorously evaluated. Previous studies that addressed this issue were not predominately focused on the preoperative ECG as a potential predictor and used very general definitions for ECG abnormalities.[5,15] Our present study uses strict and detailed definitions for 12-lead ECG abnormality, based on the Sokolow-Lyon criteria for left ventricular hypertrophy. In addition, to more thoroughly examine the association between preoperative ECG abnormalities, perioperative myocardial ischemia, and postoperative cardiac complications, we used data from two independent prospective studies on major vascular surgery patients.

METHODS

Data from two unrelated prospective studies on major vascular surgery patients, performed at Hadassah Hospital, Jerusalem, Israel, and the Johns Hopkins Hospital, Baltimore, Md., were analyzed both separately and with all patients combined. Both study protocols were approved by the hospitals' ethics committee, and all patients gave informed consent.

Hadassah Hospital. A total of 305 consecutive patients who underwent elective carotid endarterectomy (115 patients, 37.7%), repair of the abdominal aorta (68 patients, 22.3%), or lower extremity revascularization (122 patients, 40%) from 1991 through 1994 were enrolled. Twelve additional patients were excluded: four because of left bundle branch block and eight as a result of poor-quality Holter recording. None of the 12 excluded patients had adverse postoperative cardiac events.

Patients were assessed at the preoperative evaluation clinic and examined both before and after surgery by a cardiology consultant for signs or symptoms of cardiac complications. All patients remained in the intensive care unit (ICU) or the postanesthesia care unit for at least 24 hours. Routine 12-lead ECGs were recorded before surgery, daily for the first 3 postoperative days, before discharge, and whenever clinically indicated. Serum creatine kinase and its MB isoenzyme were measured before surgery, every 6 hours after surgery for the first 24 hours (or as long as the patient stayed in the ICU), once daily through postoperative day 3, and whenever clinically indicated. Oral preoperative cardiac and antihypertensive medications were maintained before surgery and resumed as soon as possible after surgery. Blood pressure was monitored intraarterially, and all aortic surgery patients were managed with a pulmonary artery catheter. Postoperative analgesia was provided by epidural or intravenous narcotic treatment.

Holter recordings were started on the day before surgery and were continued through surgery and day 1 after surgery (total recording time of 45.5 ± 6.4 hours; range, 24 to 62 hours). Three bipolar ECG channels (modified V_4, V_5, and aVF) were obtained using an amplitude-modulated recorder (series 8500, Marquette Electronics, Milwaukee, Wis.) and were analyzed with a Marquette 8000 computerized playback unit, as previously reported.[16] Periods of ST-segment depression of at least 0.1 mV (1 mm), or ST-segment elevation of at least 0.2 mV, lasting for more than 1 minute were disclosed for visual interpretation by an investigator who was blinded to the clinical course of the patients. In patients with baseline T wave inversions or ST segment depressions, the definition of an ischemic episode required that both the J point and ST segment fell at least 0.1 mV below their baselines.

Johns Hopkins Hospital. Data from 100 patients who had been enrolled in the Perioperative Ischemia–Randomized Anesthesia Trial (PIRAT)[16-18] were analyzed. Those patients who underwent elective lower extremity arterial bypass procedures between 1988 and 1991 were randomized to either epidural or general anesthesia. Of 184 patients screened, six were excluded as a result of left ventricular hypertrophy with strain pattern including ST depression 1 mm or greater on preoperative ECG. The others were excluded as a result of contraindications to either epidural or general anesthesia or because of refusal for randomization.

All clinical data were gathered prospectively. History of angina pectoris was obtained using a previously validated questionnaire that was designed for vascular surgery patients,[19] supplemented by the reports of the admitting clinicians. Invasive hemodynamic monitoring and fluid management were controlled by a protocol that was individualized to each patient's medical condition, as previously reported.[19] All patients were admitted to the ICU after surgery, where they received either epidural or intravenous patient-controlled analgesia. Invasive monitoring, fluid administration, and transfusion protocols remained in effect until discharge from the ICU. ECGs were obtained before surgery, daily through postoperative day 3, and on day 7. Creatine kinase and MB isoenzyme were checked every 6 hours on the day of surgery, once daily through day 3, and whenever clinically indicated.

Perioperative myocardial ischemia was monitored using Q-Med digital monitors (DelMar Avionics, Cincinnati; Q-Med, Inc., Lawrence, N.J.), in leads V5 and II (or III if the voltage was inadequate), as previously published.[17] Total recording time was 44.7 ± 11.5 hours (range, 16 to 90 hours). Myocardial ischemia was defined as reversible, horizontal or downsloping ST segment depression 1 mm or greater, or ST elevation 2 mm or greater, compared with baseline in one or more leads and lasting for at least 1 minute.

Adverse cardiac outcomes. In both hospitals two postoperative ischemic cardiac complications were included as adverse outcomes: (1) cardiac death as a result of myocardial infarction, congestive heart failure, or arrhythmia; and (2) myocardial infarction, based on the existence of at least two of the following criteria: (a) elevated creatine kinase above twice its normal level and elevated creatine kinase MB isoenzyme (>5% at Hadassah Hospital and >3% in Johns Hopkins Hospital); (b) either new Q-waves or persistent (≥72 hours) new ST-T wave changes by 12-lead ECG (Minnesota code[20]); and (c) prolonged (>30 minutes) typical chest pain.

Preoperative 12-lead ECG analysis. All of the preoperative ECGs (n = 405) were analyzed in each center by two investigators who were blinded to the patients' clinical course and outcome. Cases in dispute were resolved by agreement. Pathologic Q-waves were identified by using the Minnesota Code.[16] Based on the Sokolow-Lyon[21] criteria for left ventricular hypertrophy, three additional categories of ECG changes were recorded: (1) Voltage criteria for LVH, which included one of the following: R wave in lead I + S wave in lead III ≥25 mm, R wave in V_5 or V_6 >26 mm, R wave in lead aVL >11 mm, or R in V_5 + S in V_1 ≥35 mm; (2) ST-segment depression, which was identified as such if it was >0.5 mm below the isoelectric (PR) level in any lead except the right side leads: III, aVR, or V_1; and (3) T-wave inversion, which was so diagnosed if it occurred in any lead except III, aVR, or V_1.[21]

Statistical analysis. χ^2 and univariate logistic regression analyses (for categorical and continuous variables) were used to correlate potential predictors of outcome and postoperative cardiac events. The odds ratios, 95% confidence intervals, and p values were calculated. The outcome predictors that were of statistical significance ($p < 0.05$) were subjected to multivariate logistic regression analyses, with special priority given to preoperative clinical variables (history of myocardial infarction and angina pectoris) even if they did not reach statistical significance by univariate analysis. Two multivariate logistic regression models were evaluated: one included only preoperative predictors of outcome, whereas the other also included the duration of intraoperative and postoperative ischemia. The Mann-Whitney nonparametric test was used to compare variables with skewed distribution (e.g., duration of ischemia).

RESULTS

The differences and similarities in demographic and clinical characteristics, as well as the prevalence of preoperative ECG abnormalities and perioperative myocardial ischemia, of the patient groups from both medical centers are given in Table I.

Postoperative cardiac complications. Postoperative cardiac complications occurred in 13 patients (4.3%) in the Hadassah group and six patients (6%) in the Johns Hopkins group. In both centers combined, there were two cardiac deaths and 17 acute nonfatal myocardial infarctions, most of them of the non–Q-wave type (12 of 17 patients). One death occurred less than 12 hours after surgery after pro-

Table I, A. Perioperative characteristics of study populations

	Hadassah Hospital		*Johns Hopkins Hospital*		
	No.	*(%)*	*No.*	*(%)*	*p*
Age (yr)	66.7 ± 9.7		64.9 ± 11.3		0.13
Sex (male/female)	212/93	(69/31)	57/43	(57/43)	0.03
Cardiac history					
MI	99	(32.4)	24	(24)	0.14
AP	82	(26.9)	21	(21)	>0.2
History of IHD: MI and/or AP	153	(50.2)	33	(33)	0.002
Congestive heart failure	28	(9.2)	10	(10)	>0.2
Cardiac risk factors					
Diabetes mellitus	103	(33.8)	35	(35)	>0.2
Hypertension	205	(67.2)	63	(63)	>0.2
Medications					
Nitrates	83	(27.2)	9	(9)	0.0001
β-blockers	66	(21.6)	16	(16)	>0.2
Ca^{++}-blockers	137	(44.9)	24	(24)	0.0002
Digoxin	11	(3.6)	11	(11)	0.005
12-lead ECG					
Pathological Q-waves	56	(18.4)	21	(21)	>0.2
Voltage criteria for LVH	62	(20.3)	16	(16)	>0.2
ST-depression >0.5 mm	64	(20.9)	34	(34)	0.008
T-wave inversion	98	(32.1)	31	(31)	>0.2
Voltage criteria and/or ST-depression	97	(31.8)	37	(37)	>0.2
Holter ischemia					
Preoperative	73	(23.9)	8	(8)	0.0005
Intraoperative	67	(22.0)	12	(12)	0.03
Postoperative	113	(37.1)	16	(16)	0.0001

MI, Myocardial infarction; *AP,* angina pectoris; *IHD,* ischemic heart disease; *LVH,* left ventricular hypertrophy.

Table I, B. Duration of ischemia

	Hadassah Hospital			*Johns Hopkins Hospital*			
Ischemia duration (min)	*Mean ± SD*	*Median*	*IQR*	*Mean ± SD*	*Median*	*IQR*	*p*
Preoperative	80 ± 76	50	97	32 ± 42	19	37	0.02
Intraoperative	74 ± 91	40	105	27 ± 35	14	27	0.02
Postoperative	132 ± 218	55	110	131 ± 261	28	172	0.11
Intraoperative and postoperative	137 ± 220	45	130	122 ± 239	35	119	>0.2

IQR, interquartle range.

longed myocardial ischemia (>5 hours).[22] An additional patient died of sudden cardiac arrest a short time after the termination of surgery after prolonged intraoperative ischemia.

Correlates of cardiac complications. A preoperative history of angina pectoris, diabetes mellitus, and treatment with nitrates, calcium channel blockers, or digoxin were the only clinical variables associated with postoperative cardiac complications in the Hadassah group, but not in the Johns Hopkins group (Table II). Preoperative ECG findings correlated with postoperative cardiac complications: 10 of the 19 patients (52.6%) who had cardiac events met the voltage criteria for left ventricular hypertrophy (odds ratio, 5.2; $p = 0.002$); 11 patients (57.9%) who had postoperative events exhibited baseline ST segment depression (odds ratio, 4.7; $p = 0.0005$); and 15 patients (78.9%) who had cardiac events met voltage criteria, ST depression criteria, or both by preoperative ECG (odds ratio, 8.4, $p = 0.00001$). Voltage criteria, ST segment depression, or both conferred sevenfold to ninefold odds of having a postoperative cardiac complication. Pathologic Q-waves and T wave inversion were not associated with postoperative cardiac events (Table II).

The duration of perioperative ischemia was associated with postoperative complications. The combined duration of intraoperative and postoperative ischemia was significantly associated with cardiac complications in each group and in both groups

Table II. Univariate analysis of preoperative variables associated with postoperative infarction or cardiac death

	Hadassah Hospital (n = 305)			*Johns Hopkins Hospital (n = 100)*		
	No. (%) of patients with variable who had event	*Odds ratio (confidence interval)*	*p*	*No. (%) of patients with variable who had event*	*Odds ratio (confidence interval)*	*p*
Age ≥70 yr	5 (3.9)	0.8 (0.2-2.6)	>0.2	3 (8.6)	1.9 (0.3-10.5)	>0.2
Preoperative MI	6 (6.1)	1.8 (0.5-5)	>0.2	1 (4.2)	0.6 (0.06-5)	>0.2
Angina pectoris	7 (8.5)	3.3 (1.1-10.1)	0.02	1 (4.8)	0.7 (0.1-6.6)	>0.2
CHF	2 (7.1)	1.8 (0.4-8.8)	>0.2	1 (10.0)	1.8 (0.2-17)	>0.2
IHD:MI/AP	10 (6.5)	3.3 (0.9-12.5)	0.05	2 (6.1)	1.0 (0.2-5.8)	>0.2
Diabetes mellitus	8 (7.8)	3.3 (1.1-10.4)	0.03	3 (8.6)	1.9 (0.4-10.1)	>0.2
Hypertension	11 (5.4)	2.8 (0.6-12.8)	>0.2	4 (6.3)	1.2 (0.2-6.8)	>0.2
Current medications:						
Nitrates	7 (8.4)	3.2 (1.1-10.1)	0.03	1 (11.1)	2.1 (0.2-20.7)	>0.2
β-blockers	5 (7.6)	2.3 (0.7-7.4)	0.13	1 (6.3)	1.0 (0.1-9.5)	>0.2
Ca-blockers	10 (7.3)	4.3 (1.1-15.9)	0.02	1 (4.2)	0.6 (0.1-5.5)	>0.2
Digoxin	2 (18.2)	5.7 (1.1-29.6)	0.02	1 (9.1)	1.7 (0.2-15.8)	>0.2
Preoperative 12-lead ECG						
Pathological Q-waves	4 (7.1)	2.0 (0.6-6.9)	>0.2	2 (9.5)	1.9 (0.3-11.1)	>0.2
Voltage criteria of LVH	7 (11.3)	5 (1.6-15.5)	0.002	3 (20.0)	6.2 (1.1-32)	0.02
ST-dep. > 0.5 mm	6 (9.4)	3.5 (1.1-10)	0.02	5 (14.7)	11.2 (1.3-100)	0.008
T-wave inversion	6 (6.1)	1.8 (0.6-5.7)	>0.2	4 (12.9)	4.9 (0.8-28.0)	0.06
Voltage and/or ST dep.	10 (10.3)	7.8 (2.1-29)	0.0003	5 (13.5)	9.6 (1.2-86.5)	0.015
Preoperative Holter monitoring						
Occurrence of ischemia	7 (9.6)	3.9 (1.3-12.3)	0.01	1 (12.5)	2.5 (0.25-24.3)	>0.2
Ischemia duration		1.2*	0.0002		1.7*	0.04

*Odds ratio per 1 minute of ischemia.
MI, Myocardial infarction; *CHF,* congestive heart failure; *IHD,* Ischemic heart disease; *AP,* angina pectoris; *LVH,* left ventricular hypertrophy; *ST-dep,* ST depression.

together (odds ratio, 14.2; $p = 0.00001$). Most cardiac complications (89.5%) were preceded by postoperative ischemia on Holter monitoring. The combined results indicate that the cumulative duration of intraoperative and postoperative ischemia was significantly longer in patients who had postoperative cardiac events than in those who did not (466 ± 457 minutes vs 33 ± 82 minutes; median, 330 vs 0 minutes respectively; $p < 0.0001$). In 54.2% of the patients with postoperative cardiac events, the intraoperative and postoperative ischemia duration was longer than 2 hours. Intraoperative and postoperative ischemia was also more prolonged in patients with voltage criteria, ST segment depression, or both on preoperative ECG (Table III).

Two multivariate logistic regression models were used to analyze the relative importance of different predictors of cardiac complications (Table IV). The first model, which included only the preoperative predictors, indicated that preoperative ischemia, ischemia duration, and the preoperative 12-lead ECG abnormality (with voltage criteria, ST segment depression, or both) were independently associated with postoperative cardiac events. The second model included also the cumulative intra and postoperative ischemia duration. It showed that only the duration of intraoperative and postoperative ischemia and the preoperative ECG abnormality (voltage criteria, ST depression, or both) were independently associated with postoperative cardiac outcome (Table IV). Similar results, showing that duration of intraoperative and postoperative ischemia and preoperative voltage or ST segment depression were the only variables associated with postoperative cardiac complications, were obtained even when all 22 patients (5.4%) treated with digoxin were excluded from the study ($p < 0.0002$ and $p = 0.04$, respectively).

DISCUSSION

Only a few prospective studies have explored the value of using preoperative 12-lead ECG in predicting postoperative cardiac complications.[2] In two studies, ischemic or nonspecific ST-T wave changes on preoperative ECGs were better preoperative predictors of adverse postoperative cardiac outcome than either exercise stress testing,[5] a history of preoperative myocardial infarction, or Q-wave on ECG.[23] Conversely, other investigations have found that

Table III. Intraoperative postoperative myocardial ischemia correlated with preoperative variables—combined group

	Patients with ischemia (%)	*p**	*Ischemia duration (min per hr monitored) (median [IQR])†*	*p‡*
History of IHD:				
no	71 (33.0)		4.6 ± 7.4 (1.8 [4.8])	
yes	90 (48.4)	0.002	4.7 ± 7.9 (1.5 [4.8])	>0.2
Hypertension:				
no	51 (37.2)		1.5 ± 5.1 (0 [0.7])	
yes	111 (41.1)	>0.2	2.1 ± 5.5 (0 [1.2])	>0.2
Diabetes:				
no	100 (37.5)		1.7 ± 4.6 (0 [1.2])	
yes	62 (44.9)	0.14	2.1 ± 6.5 (0 [1.0])	0.12
Preoperative 12-lead ECG				
Q-waves:				
no	137 (41.8)		4.6 ± 7.7 (1.5 [4.4])	
yes	25 (32.5)	0.13	5.1 ± 7.6 (1.5 [6.0])	>0.2
Voltage criteria for LVH:				
no	129 (39.3)		4.0 ± 6.4 (1.5 [5.6])	
yes	33 (42.9)	>0.2	7.5 ± 11.0 (3.7 [7.0])	0.04
ST segment depression:				
no	117 (38.1)		4.0 ± 6.6 (1.4 [4.2])	
yes	45 (45.9)	0.17	6.4 ± 9.7 (2.6 [5.0])	0.02
T wave inversion:				
no	103 (37.3)		4.3 ± 7.1 (1.4 [4.4])	
yes	59 (45.7)	0.11	5.3 ± 8.6 (2.0 [4.9])	0.11
Voltage criteria for LVH and/or ST depression:				
no	102 (37.6)		3.4 ± 4.7 (1.4 [4.2])	
yes	60 (44.8)	0.17	6.8 ± 10.7 (2.2 [5.2])	0.04

*χ^2 test.
†Cumulative ischemia in patients with ischemia.
‡Mann-Whitney test.
IQR, Interquartile range; *IHD,* ischemia heart disease; *LVH,* left ventricular hypertrophy.

ECG abnormalities, including old Q-waves or ST-T changes, were not predictive of postoperative cardiac complications.[15,24] Currently, the guidelines of the American College of Cardiology and the American Heart Association for preoperative cardiac assessment recommend that in the general patient population undergoing noncardiac surgery, preoperative ECG abnormalities are only a minor predictor of perioperative cardiac complications.[4]

Our present data from two independent prospective studies show that in selected high-risk group of patients, such as those undergoing major vascular surgery, voltage criteria for left ventricular hypertrophy and ST segment depression greater than 0.5 mm are important markers of postoperative myocardial infarction or cardiac death. The two patient groups presented here were from two unrelated vascular surgery cohorts. They had different preoperative demographic and clinical features (Table I) and different study protocols in regard to perioperative patient management. Nevertheless, both studies showed similar correlations between preoperative ECG abnormalities, perioperative myocardial ischemia, and postoperative cardiac outcome. Prolonged cumulative intraoperative and postoperative ischemia was most significantly associated with cardiac events, in accordance with previous reports.[11,12,25] The preoperative voltage criteria and ST depression, however,

Table IV. Multivariate logistic-regression analysis of variables associated with postoperative myocardial infarction and cardiac death

	Model 1		*Model 2*	
Variables	*Odds ratio*	*p*	*Odds ratio*	*p*
History of IHD	1.2	>0.2	1.1	>0.2
Preoperative 12-lead ECG				
Pathological Q-waves	1.4	>0.2	2.5	0.19
Voltage criteria and/or ST segment depression	5.8	0.004	4.9	0.02
Holter-monitored ischemia				
Preoperative ischemia	6.8	0.01	3.1	0.19
Preoperative ischemia duration	1.006*	0.05	1.0005*	0.19
Intraoperative and postoperative ischemia duration	—	—	1.007*	<0.0001

IHD, Ischemic heart disease.
*Odds ratio per minute ischemia.

had an additional independent association with postoperative cardiac outcome, by multivariate analysis (Table IV). All other preoperative predictors, such as a history of ischemic heart disease, hypertension, diabetes mellitus, pathologic Q-waves, or T wave inversion on the preoperative ECG, were not independently associated with adverse cardiac events.

Left ventricular hypertrophy, a major marker of cardiovascular morbidity and death in the nonoperative setting,[13,26] is associated with a marked increase in all clinical manifestations of coronary artery disease, including myocardial infarction and sudden cardiac death. The hypertrophic left ventricle is more vulnerable to myocardial hypoperfusion caused by exercise in the presence of coronary artery stenosis[27] and results in larger infarct size with experimental coronary occlusion in animal models.[28] Mechanisms such as an increase in left ventricular filling pressure during stress, left ventricular endothelial and microvascular dysfunction,[29] impaired coronary vasodilator reserve,[30] and increased subendocardial metabolic demand[31] have all been shown to increase the susceptibility of the hypertrophic heart to ischemia. In the presence of coronary artery disease, the hypertrophic heart is particularly vulnerable to circumstances common in the perioperative period such as anemia,[32] hypotension, and tachycardia.[33]

Voltage criteria are specific for left ventricular hypertrophy (>90%),[21] yet their sensitivity is relatively low, varying from 45% to 80% when compared with autopsy[21,34] and as low as 6.9% when contrasted with echocardiography.[35] This is a result of factors such as obesity, breast tissue, and pulmonary emphysema known to impede the electric conductance through the chest wall.[26] Conversely, an ST segment depression greater than 0.5 mm, with or without T wave inversion, was the most common finding (92.5%) in left ventricular hypertrophy in the Sokolow-Lyon study[21] as well as in more recent ones.[36,37]

ST segment abnormality not caused by left ventricular hypertrophy also indicates a poor prognosis in patients with or without known coronary artery disease.[38] Patients who have ischemic heart disease and ST-T wave abnormalities have more extensive disease and a worse prognosis than patients who have a normal ST-T wave pattern.[14,39] The percentage of patients with ST-T abnormalities increases with age, the number of diseased coronary vessels, a decline in left ventricular ejection fraction, and progression of regional contraction abnormalities.[40,41] Patients with significant obstruction of the left anterior descending coronary artery alone, or in combination with other lesions, are particularly likely to have ST-T abnormalities.[42]

Left ventricular hypertrophy by preoperative ECG was the most important preoperative predictor of postoperative, Holter-detected, myocardial ischemia in one large-scale study.[43] Other studies have repeatedly shown that postoperative myocardial ischemia, especially if prolonged, is significantly associated with postoperative cardiac complications.[10,11,25,44] Our data support these observations and further demonstrate that preoperative ECG abnormalities, based on the Sokolow-Lyon criteria for left ventricular hypertrophy, are associated both with intraoperative and postoperative ischemia of longer duration and with postoperative myocardial infarction or cardiac death.

These findings suggest two important implications: (1) the preoperative ECG delineates a subgroup of patients (33% of those who undergo vascular surgery) in whom most of the cardiac complications (80%) occur. If additional more-sophisticated preoperative testing, such as thallium-dipyridamole scanning or dobutamine echocardiography, are considered, they may be limited mostly to this subgroup of patients; and (2) conceptually, the data support the hypothesis that prolonged perioperative ischemia is a main mechanism for postoperative cardiac complications.[11] Although rupture of an unstable atheromatous coronary plaque is the most common cause for myocardial infarction and ischemic cardiac events that occur in the nonsurgical setting, several lines of evidence suggest a different mechanism for the postoperative infarction: ST-segment elevation is extremely rare after noncardiac surgery, and the postoperative infarctions are accompanied by ST-segment depression rather than elevation[10,11,44]; most postoperative myocardial infarctions are of non–Q-wave rather than Q-wave type[11]; and prolonged ischemia by Holter monitoring is often detected in patients with postoperative infarction.[11,12,25] Moreover, plaque rupture mostly occurs (>85% of the cases) in coronary lesions that are not hemodynamically significant (stenosis <75%) before their occlusion,[45] whereas the collective data on high-risk patients undergoing surgery[10,11,44] indicate that patients with perioperative evidence of low ischemic threshold are the ones in whom postoperative cardiac complications develop and therefore are more likely to have diffuse, high-grade coronary artery lesions.

CONCLUSION

The combination of coronary artery disease and left ventricular hypertrophy is particularly likely to

precipitate ischemia during the hemodynamic stresses of vascular surgery and may lead to diffuse subendocardial necrosis, infarction, or death. The preoperative ECG with evidence of voltage criteria for left ventricular hypertrophy or ST segment depression greater than 0.5 mm may serve as a marker for the high-risk individual undergoing major surgery.

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